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High-resolution 3D seismic investigations of the overburden above potential CCS sites of the inner Texas shelf, Gulf of Mexico, U.S.A.

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Abstract

Much CCS research has focused on the injection interval (storage reservoir) and the immediately overlying primary seal. Considerations related to potential long-term leakage have turned attention toward the geologic overburden between the primary seal and shallow intervals containing protected groundwater. Typically the overburden interval is poorly imaged in commercially available seismic data given acquisition and processing optimized for deeper reservoir systems. Recent advances in high-resolution 3D (HR3D) seismic imaging have allowed for more thorough investigation of this critical interval in marine settings, and are well-suited for evaluating potential leakage pathways for prospective CCS sites. HR3D datasets can serve to reduce risks prior to project development as well as provide containment assurance via staggered time-lapse surveys. HR3D is likely to become a fundamental technology in offshore CCS.

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1. Introduction

A multi-year study characterizing prospective CO_2 storage sites in shallow Gulf of Mexico waters utilized a high-resolution multi-streamer "P-Cable" marine seismic acquisition system to complement existing commercial 3D data by linking the shallow and deep geologic systems for unified interpretation. Three surveys in Texas State Waters have been conducted in 2012, 2013, and 2014 (totalling over 130 sq. km; Table 1). These survey locations occur along the heavily-industrialized portion of the upper Texas coast, which includes large coal-fired electricity generation, CO_2 pipeline development for CO_2-EOR, prior investments in anthropogenic CO_2 capture (Air Products hydrogen plant in Port Arthur), and some of the largest developing energy projects in the United States (LNG export, methanol, and heavy oil refining via the Keystone XL pipeline (Figure 1).

HR3D data can be used to: 1) characterize any shallow (~1km depth) storage formations prior to initiating a project; 2) characterize the overburden above storage formations by providing stratigraphic and structural information for risking long-term storage and avoiding unintended migration, and 3) serve as a baseline for future time-lapse (4D) surveys to demonstrate containment or identify non-containment.

Nomenclature

HR3D	High Resolution Three-Dimensional Reflection Seismic Data
TWTT	Two-way travel time (msec = millisecond)
GI	Generator-Injector compressed air acoustic source

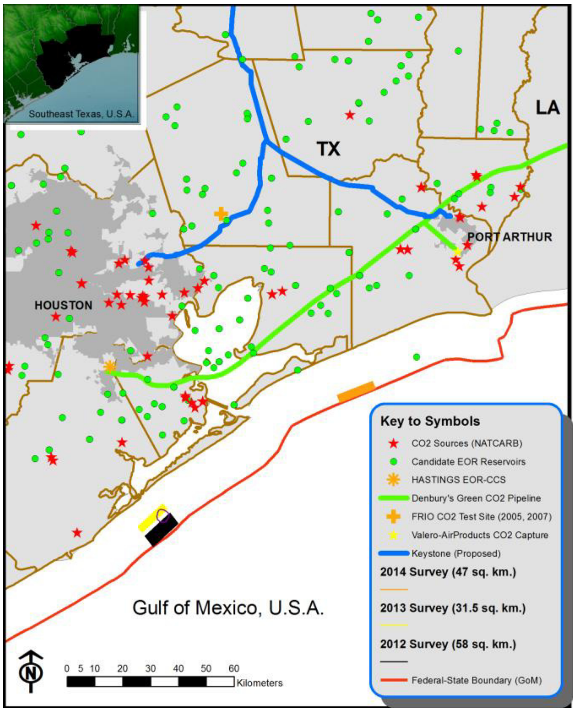

Fig. 1. Locations of HR3D surveys off the Texas Coast over 2012-2014. Note the heavily-industrialized coastal zone, including large CO_2 emissions sources (red stars, including coal-fired electricity generation), CO_2 pipeline development for CO_2-EOR (green line), prior investments in anthropogenic CO_2 capture (Air Products hydrogen plant in Port Arthur, yellow star), and some of the largest developing energy projects in the United States (LNG export, methanol, and heavy oil refining via the Keystone XL pipeline (blue line)). The area also hosts the Frio (orange plus) and Hastings (orange asterisk) CCS Projects. The region is a nexus of energy development and CO_2 activity.

1.1. HR3D Acquisition System

The acquisition system used in this research was developed since 2001 in Norway via the Oslo Innovation Centre, in collaboration with the University of Tromso. Five systems are operational globally, but this research represents the first use of the technology in the Gulf of Mexico. Table 1 provides the basics information for each survey, followed by a list of basic equipment specifications.

Table 1. Survey details for the three HR3D seismic surveys. Sources are compressed air Generator-Injector airguns.

DATE	TX LOCATION	AREA (sq. km.)	LINE KM	AIRGUN SOURCE
July, 2012	San Luis Pass	58	1,077	Two 210 cu. in. GI
October, 2013	San Luis Pass	31.5	420	One 90 cu. in. GI
April, 2014	High Island	47	627	Two 90 cu. in. GI

The acquisition system specifications are:

- 12 active sections (streamers): GeoEel Solid
- 25 m streamer length (short offset, low fold)
- 8 Channels per streamer (96 total)
- Streamer separation: 12.5m
- Source: Sercel GI Airguns
- 12.5 m shot spacing (6.25 m^2 bins)
- Dominant frequency: 150 Hz (50-250 Hz typical)
- Navigation and positioning: 3rd party navigation hardware/software with proprietary processing

Acquisition utilized twelve 25-m long streamers with 12.5 m lateral spacing, each with 8 receivers at 3 m spacing (total 96 channels). Data collected in this study are termed 'high-resolution' due to the small bin size (6.25 m) and the relatively high dominant frequency of the recorded data (250 Hz). These characteristics allow features with horizontal resolution on the order of 5-10 meters and vertical resolution of 2-3 meters to be resolved. For comparison, conventional seismic data may be binned at 10's of meters with dominant frequencies of 25 Hz (~15 m resolution).

2. Structural interpretation

A major concern has been the potential of injected CO_2 to migrate up faults to the surface. However, it can often be difficult to map those features accurately enough to provide some estimate of risk to be evaluated. Figure 2 shows an integration of conventional 3D seismic data with HR3D data, and exhibits how fault interpretations can be confidently mapped in the critical overburden interval using HR3D data.

Interpretation of the shallow seismic data highlights the ability to map structural discontinuities from depth (potential storage intervals) toward the seafloor as well as the stratigraphic complexity that various depositional systems leave in the geologic record. The former may serve as conduits for focused and relatively rapid vertical migration, whereas the latter will serve to disperse and otherwise retard or arrest vertical migration. A thorough understanding of the relationship among these two is critical for evaluating long-term potential for migration to the seafloor, thus reducing project risks. Fault expression in the seismic data changes vertically in the stratigraphy, likely as a result of increased lithification with depth. The implications this has for fluid flow are being assessed, and simplified 2D models of fluid migration on these features highlights the importance of the contrast in flow properties between the adjacent host stratigraphy and the fault zone itself. While many of the largest-scale faults in the study area can now be mapped to intersection with the near-seafloor sediments, no examples of seafloor expression of fluid flow at fault locations are observed, suggesting the fluid system is currently inactive on the inner shelf [1].

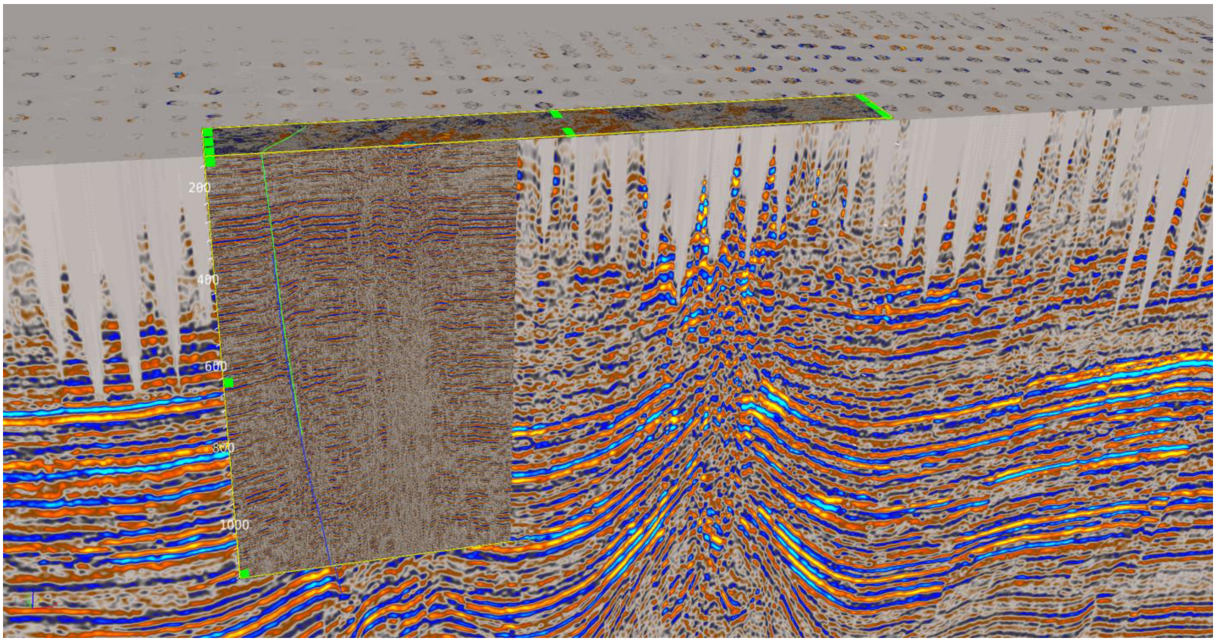

Fig. 2. Integration of conventional 3D and HR3D datasets for structural interpretation. Vertical scale is approximately 1.5 msec TWTT (perhaps 1200 m). Conventional data are typically low quality in the upper section, where HR3D data are highest quality. The fault interpretation was initiated at depth in the conventional data and carried to the seafloor in HR3D data, which would not have been possible in its absence.

3. Stratigraphic interpretation

Any CO_2 migrating toward the surface has a substantial thickness of stratigraphy to negotiate. Often that stratigraphy is poorly characterized. Due to lack of hydrocarbon resource (at least in the study area), seismic data are poor quality (Fig. 2) for shallow intervals and well logs do not cover this reason. Figure 3 provides an example of how HR3D data can illuminate the stratigraphic complexity that is likely to exist in the overburden. Vertically migrating fluids in the overburden will preferentially flow in the more permeable strata, which in some cases may have complex geometries and move CO_2 in otherwise unpredicted directions.

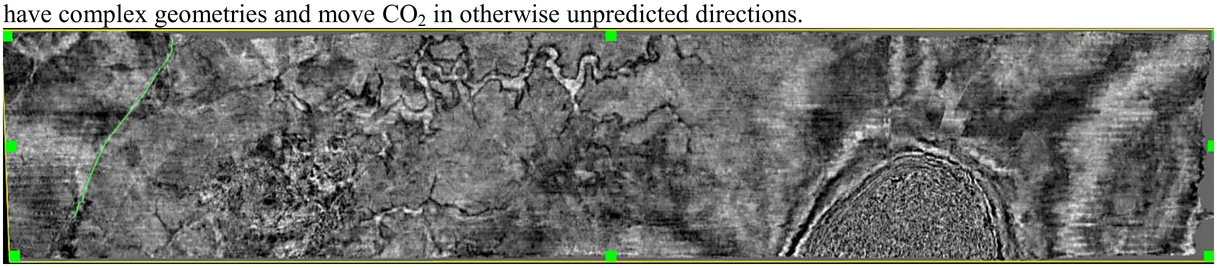

Fig. 3. Horizontal time slice at 173 msec TWTT (~130 m below sea floor) of 2013 dataset showing complex stratigraphic morphologies identifiable as sinuous fluvial depositional systems (left center). The semi-circular feature at right is a shallow salt dome with visible radiating fault patterns. The green line at left is a fault that projects from depth to very near the modern seafloor.

At relatively shallow stratigraphic depths (<500 m below seafloor), many readily recognizable depositional systems are seismically mapped in great detail in the HR3D volumes (e.g. fluvial channels, strand plains, estuaries, etc.). Mapping of these depositional systems suggests that any potentially upward migrating CO_2 would encounter a geologic labyrinth, allowing for effective stratigraphic titration (geochemical reaction) of migrating CO_2 [2]. Prior interpretations of the diagenetic history of the inner shelf of the Gulf of Mexico suggest this has been the case for natural CO_2 in the basin through geologic time[3,4]. These considerations further reduce risks to project development.

4. Summary

Three HR3D surveys covering approximately 137 sq. km. have been successfully acquired in the Gulf of Mexico. Data are highest quality in the upper 1 to 1.5 sec TWTT, and allow fault and stratigraphic geometries to be mapped in unprecedented resolution. Interpretations of these data over prospective CO_2 storage sites allow for more thorough investigation of the overburden in marine settings and provide insight into prior geologic fluid history (if any). The data are well-suited for evaluating potential leakage pathways for prospective CCS sites. HR3D datasets can serve to reduce risks prior to project development as well as provide containment assurance via staggered time-lapse surveys. HR3D is likely to become a fundamental technology in offshore CCS.

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References

[1] Cathles, L.M., Z. Su, and D. Chen, 2010. The physics of gas chimney and pockmark formation, with implications for assessment of seafloor hazards and gas sequestration, Marine and Petroleum Geology 27: 82-91.

[2] Cathles, L.M., and M. Schoell, 2007. Modeling CO_2 generation, migration, and titration in sedimentary basins, Geofluids 7: 441-450.

[3] Lundegard, P.D., and L.S. Land, 1986. Carbon dioxide and organic acids: Their role in porosity enhancement and cementation, Paleogene of the Texas Gulf Coast, In: Roles of Organic matter in sediment diagenesis (Ed. Gautier, D.L.). Special Publication of the SEPM, 38:129-146.

[4] Milliken, K.L., 2003. Late diagenesis and mass transfer in sandstone-shale sequences, Treatise on Geochemistry, p. 159-190, DOI: 10.1016/B0-08-043751-6/07091-2.